HYPOTHERMIA DURING MILITARY TRAINING: BIOMEDICAL RISK FACTORS

Andrew J. Young, Ph.D.
Thermal & Mountain Medicine Division
U.S. Army Research Institute of Environmental Medicine

RESEARCH LEADS TO DECISION A

Field Study Data

Inputs

Real-Time Data

Verification

Development

Inputs

WSM

Safety Tables

Physiological Prediction Models

Mercury System

Development

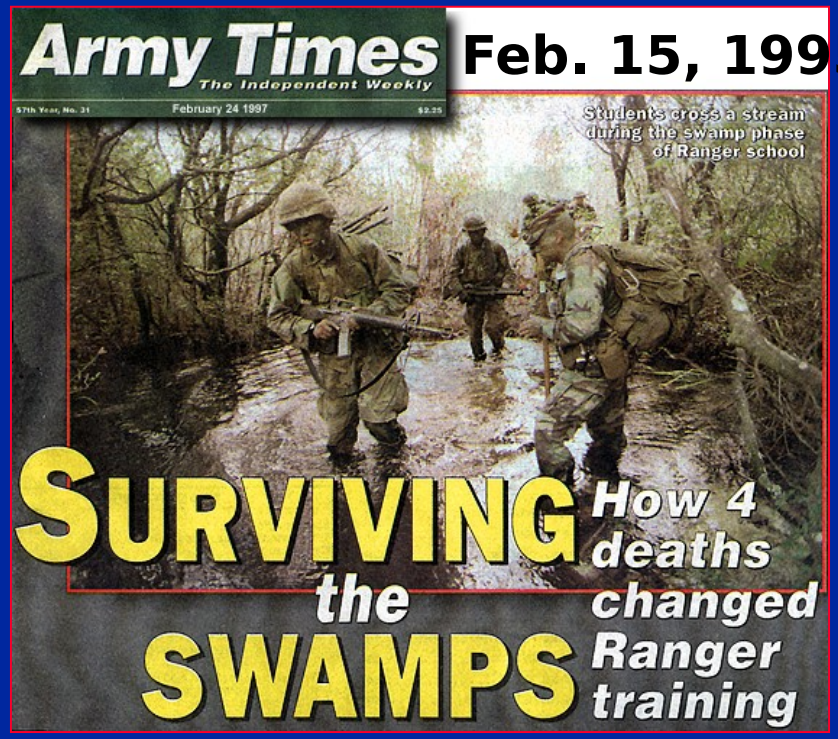
Laboratory Data

Probabilistic ⟷ Deterministic

RISK MANAGEMENT APPROACH

Cold Stress: Hypothermia

USARIEM tasked to evaluate Safety Limits


Army Times
The Independent Weekly
57th Year, No. 31
February 24 1997
$2.25
Students cross a stream during the swamp phase of Ranger school
SURVIVING the SWAMPS
How 4 deaths changed Ranger training

Feb. 15, 1995

***Response*: ✔**Lab study of immersion depths & water temperature (Lee et.al. JAP 1997) & validate pill temperature technology (O'Brien et.al. MSSE 1998).

- ✔ Developed cold water immersion model (Tikuisis et.al. JAP 1998)
- ✔ Revised cold water immersion tables
- ✔ Lab study with Rangers (Young et.al. JAP 1998)

HUMAN RESPONSES TO COLD

- **Behavioral**
  - clothing, shelter, migration
  - increase physical activity
- **Physiological**
  - peripheral vasoconstrition
  - thermogenesis

HYPOTHERMIA RISK FACTORS DUE TO:

- **Environment**

  Temperature, Wind, Rain

- **Mission**

  SUSOPS, Inactivity, Terrain, Shelter

- **Individual Characteristics**

  Fitness, Clothing, Illness, Nutrition

ENVIRONMENT

- **Temperature**

  -Wind Chill (Convection)

  -Lying on Ground (Conduction)

- **Rain**
- **Water Immersion**

Wind Speed (mi/h)	Actual Temperature (°F)											
	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
	Equivalent Chill Temperature (°F)											
Calm	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
5	48	37	27	16	6	-5	-15	-26	-36	-47	-57	-68
10	40	28	16	3	-9	-21	-33	-46	-58	-70	-83	-95
15	36	22	9	-5	-18	-32	-45	-58	-72	-85	-99	-112
20	32	18	4	-10	-25	-39	-53	-67	-82	-96	-110	-124
25	30	15	0	-15	-29	-44	-59	-74	-89	-104	-118	-133
30	28	13	-2	-18	-33	-48	-63	-79	-94	-109	-125	-140
35	27	11	-4	-20	-35	-51	-67	-82	-98	-113	-129	-145
40 [a]	26	10	-6	-22	-37	-53	-69	-85	-101	-117	-132	-148

Little Danger

Increasing Danger
(Exposed flesh freezes in 1 min)

Great Danger
(Exposed flesh freezes in 30 s)

Wind speeds greater than 40 mi/h have little additional effect.

Conductive Heat Loss

Rain/Immersion/Wet Clothing

Water conducts heat 25X greater than air

BODY TEMPERATURES DURING COLD WEATHER "CRUCIBLE" AT US MCRD, PARRIS ISLAND

Data Collection

- **CRUCIBLE Trial 1 (26-28 Jan 98)**
  - ***body composition, body weight changes, core temperatures, energy expenditure and water turnover, energy intake***
- **CRUCIBLE Trial 2 (19-21 Feb 98)**
  - ***body composition, body weight changes, core temperatures, energy expenditure & water turnover, energy intake, foot contact monitor***

Body Core Temperature Monitoring

WEATHER

- **CRUCIBLE Trial 1 (29-31 Jan 98)**
  - Mean: 51 °F, 70 %rh, no rain
  - Daily Min: 38 °F (0730), 47 °F (0315), 41 °F (0730)
  - Daily Max: 62 °F (1330), 66 °F (1530)
  - Wind: 3 mph (1-7 mph)
- **CRUCIBLE Trial 2 (19-21 Feb 98)**
  - Mean: 57 °F, 72 %rh, 0.1 in rain (2345-0700, 20/2)
  - Min: 43 °F (0645), 54 °F (0700), 45 °F (0645)
  - Max: 70 °F (1415), 71 °F (1500)
  - Wind: 3 mph (1-7 mph)

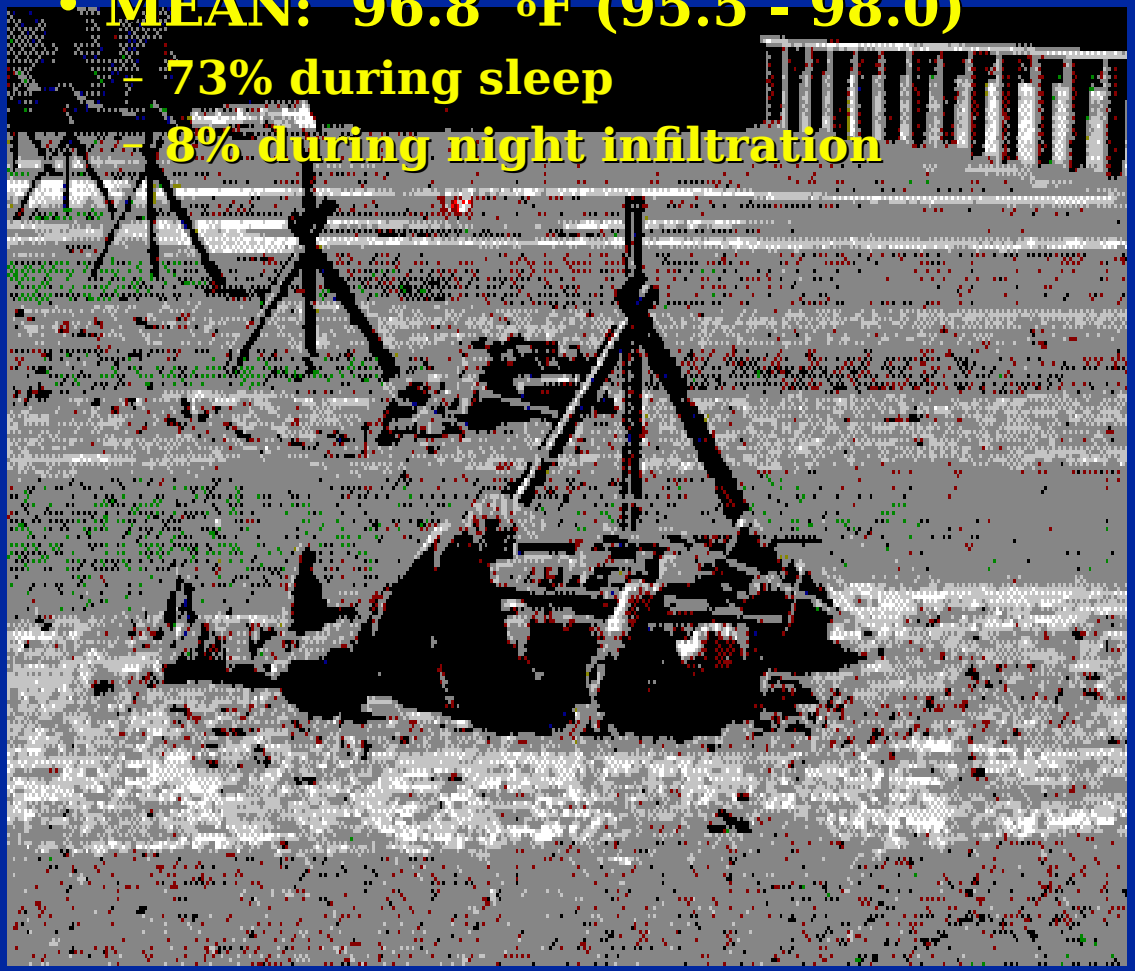
VOLUNTEERS

- N = 30
  - 20 yrs (18-26)
  - 163 lbs (135-196)
  - 16 % fat (8-21)
- n_1 = 15
- n_2 = 15

- N = 20
  - 20 yrs (18-28)
  - 130 lbs (99-162)
  - 26 % fat (20-33)
- n_1 = 10
- n_2 = 10

MINIMUM CORE TEMPERATURE DURING CRUCIBLE

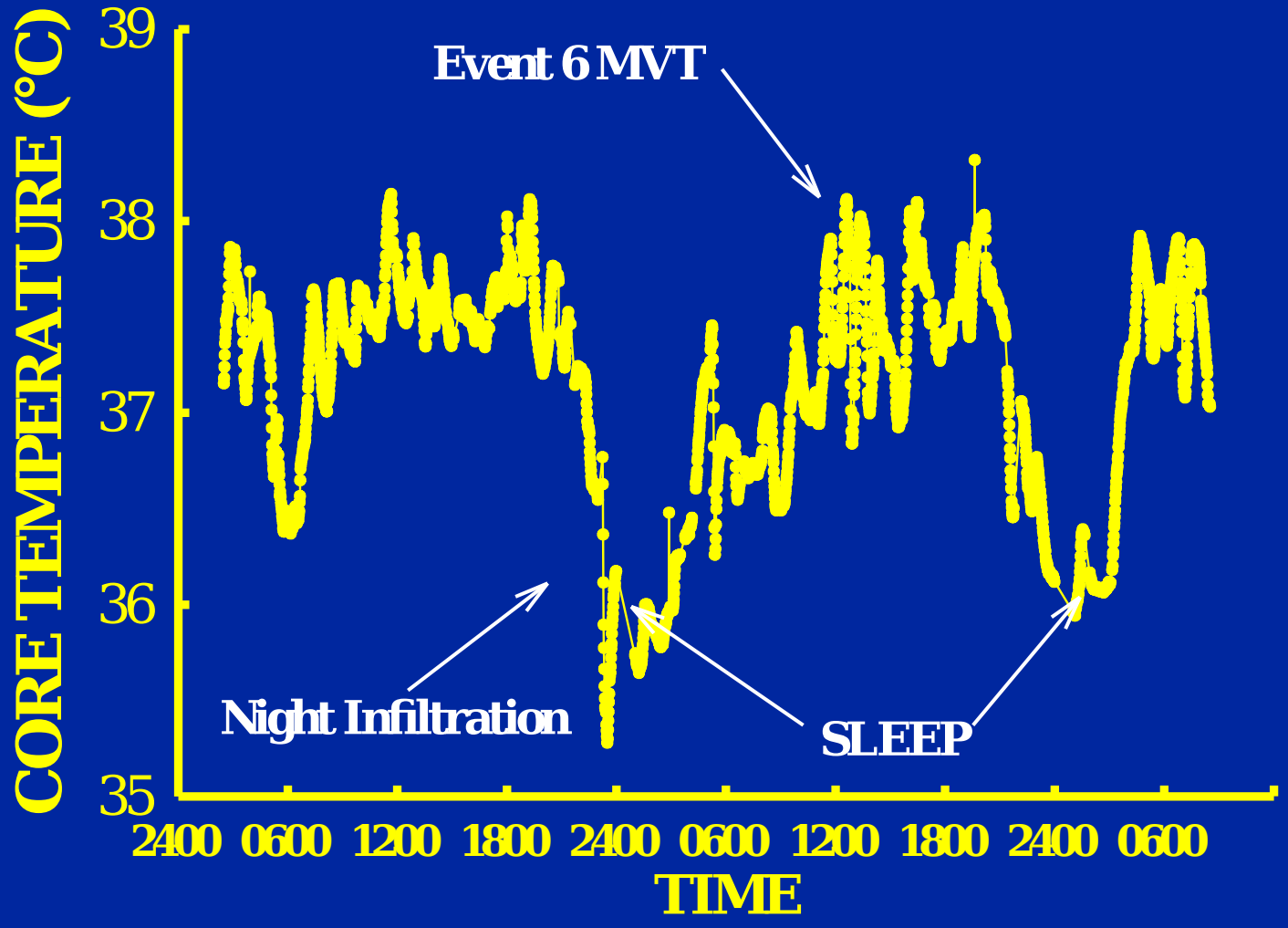
- MEAN: 96.8 °F (95.5 - 98.0)
  - 73% during sleep
  - 8% during night infiltration



CORE TEMPERATURES

		Mean High	Range	Mean Low	Range
Men					
	January (n=7)	38.51	38.15-38.56	35.63	35.28-36.39
	February (n=7)	38.69	38.33-39.14	36.13	35.43-36.64
	All Men (n=14)	38.51	38.15-39.14	35.88	35.28-36.64
Women					
	January (n=5)	38.51	38.30-38.76	36.12	35.68-36.51
	February (n=7)	38.53	38.15-38.89	36.08	35.68-36.51
	All Women (n=12)	38.52	38.15-38.89	36.08	35.68-36.51
All	(n=26)	38.51	38.15-39.14	35.97	35.28-36.64

LOWEST MINIMUM TEMPERATURE (□, 16% FAT)



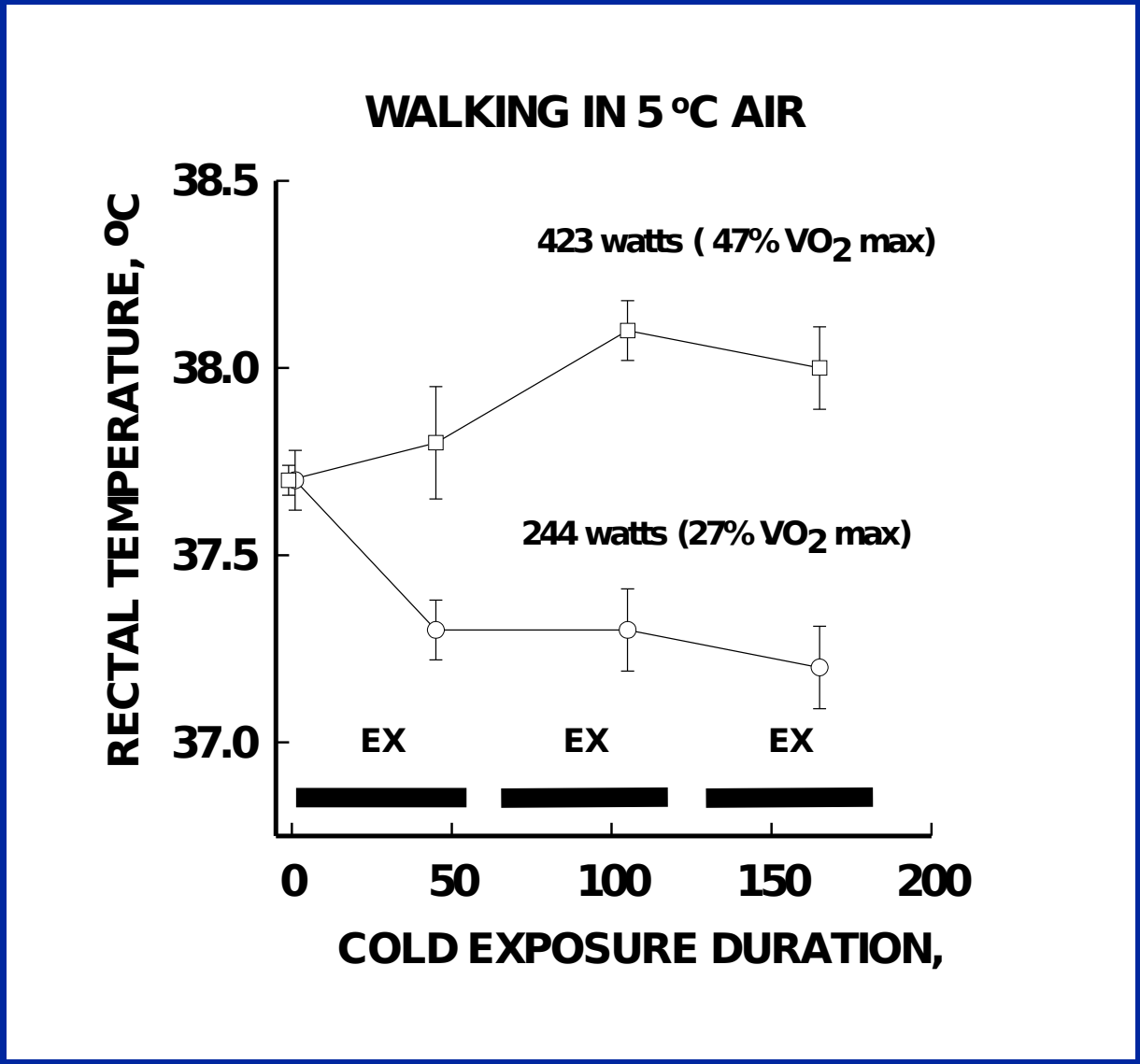
MISSION-RELATED RISK FACTORS

- **FATIGUE**
  - Sustained operations, heavy exertion, sleep deprivation, harsh terrain
- **INACTIVITY**
  - Sentry, surveillance, vehicle and weapons crew
  - Secondary to fatigue
- **REPEATED EXPOSURE**
  - Inadequate shelter, dry clothing

U.S. Army Ranger School

- 61 day course
- extreme exertion, restricte rations
- chronic negative energy balance
- sleep deprivation

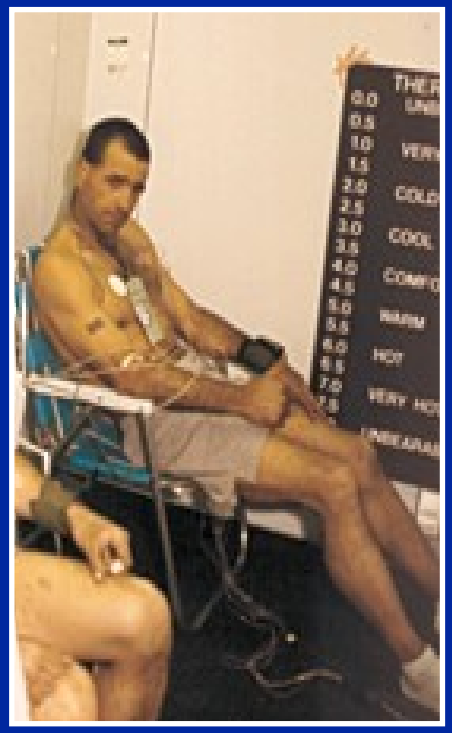
ORE TEMPERATURE & EXERCISE IN THE COL



ta from Roberts et al., Can J. Physiol. Pharmacol., 1994

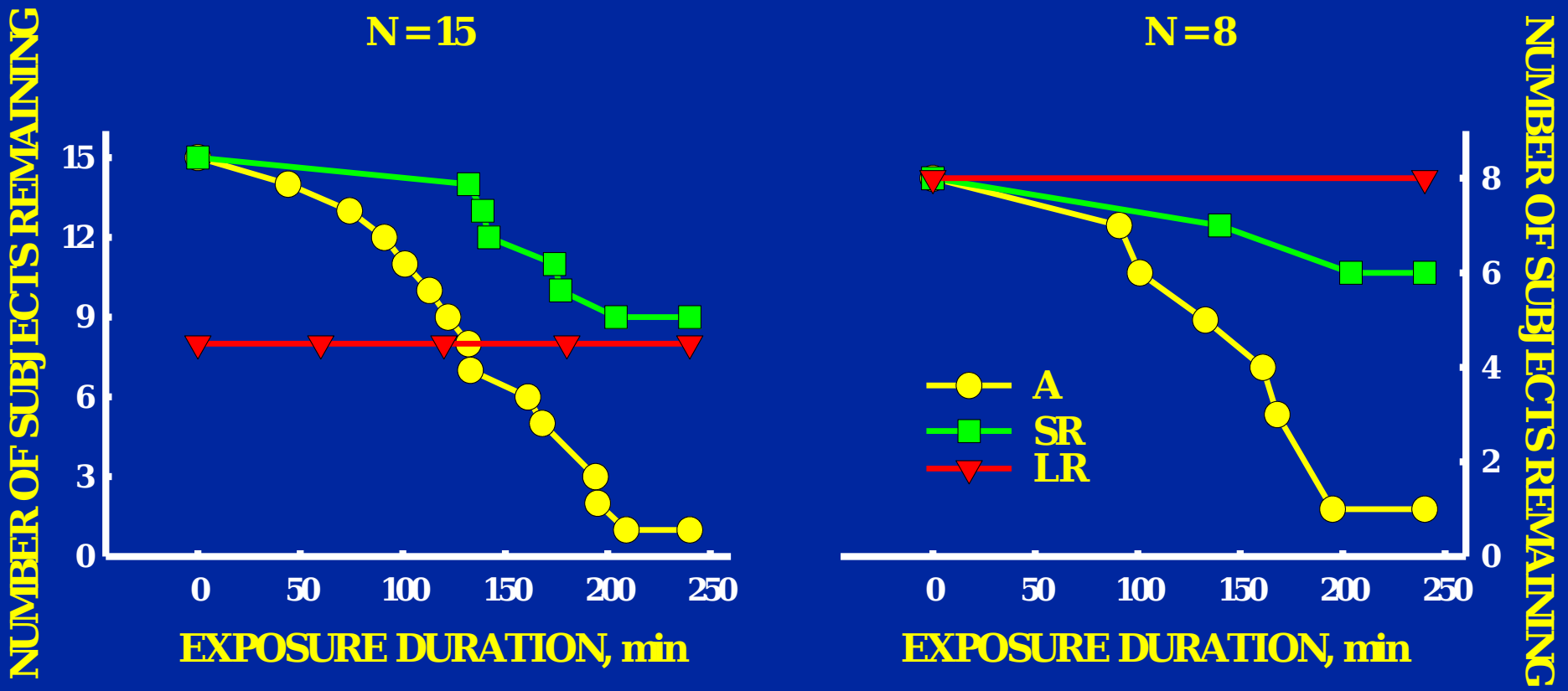
EXPERIMENTAL DESIGN

- 3 TRIALS, 15 RANGERS
  - Acute (~3 hrs after "SWAMP
  - Short recovery (48 hrs)
  - Long recovery (16 wks)

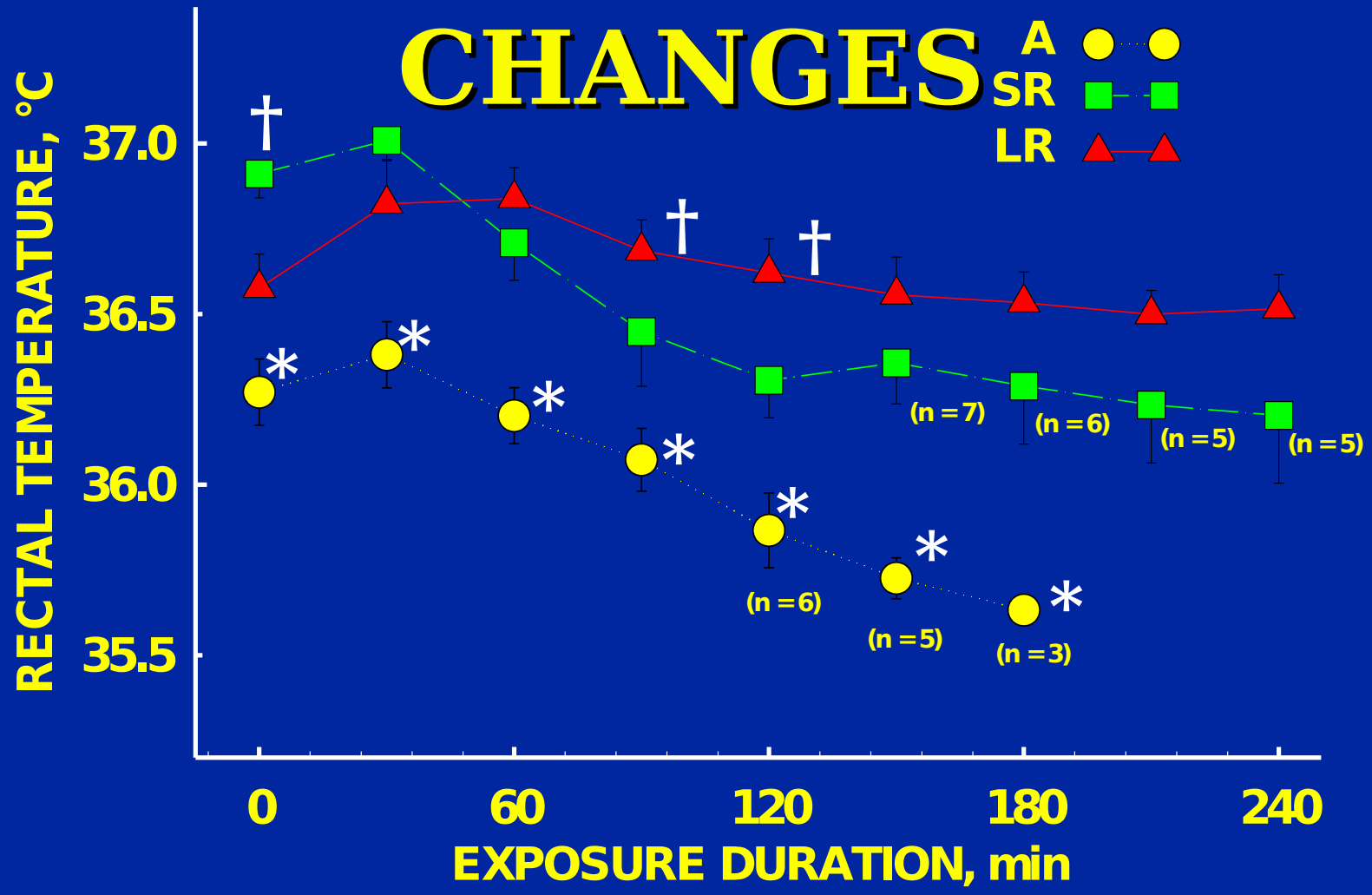


- PROTOCOL (USARIEM & NAMRL)
  - Cold air (10° C), 4-hrs, rest
  - Temperatures, metabolic rate, blood metabolites & catecholamines
- STATUS
  - Data collection completed 15 MAR 9
  - Blood assays and data analyses unde

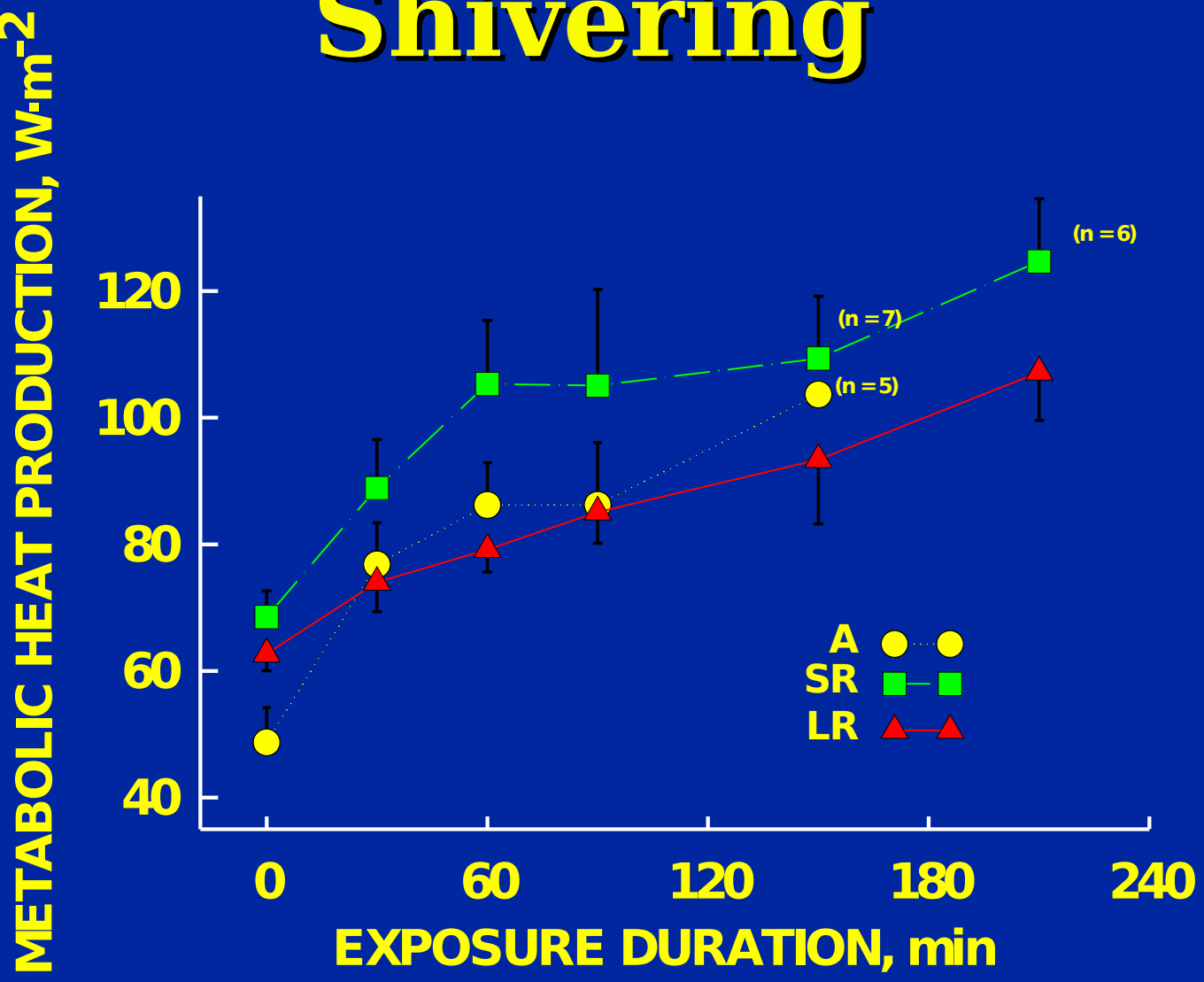
COLD TOLERANCE



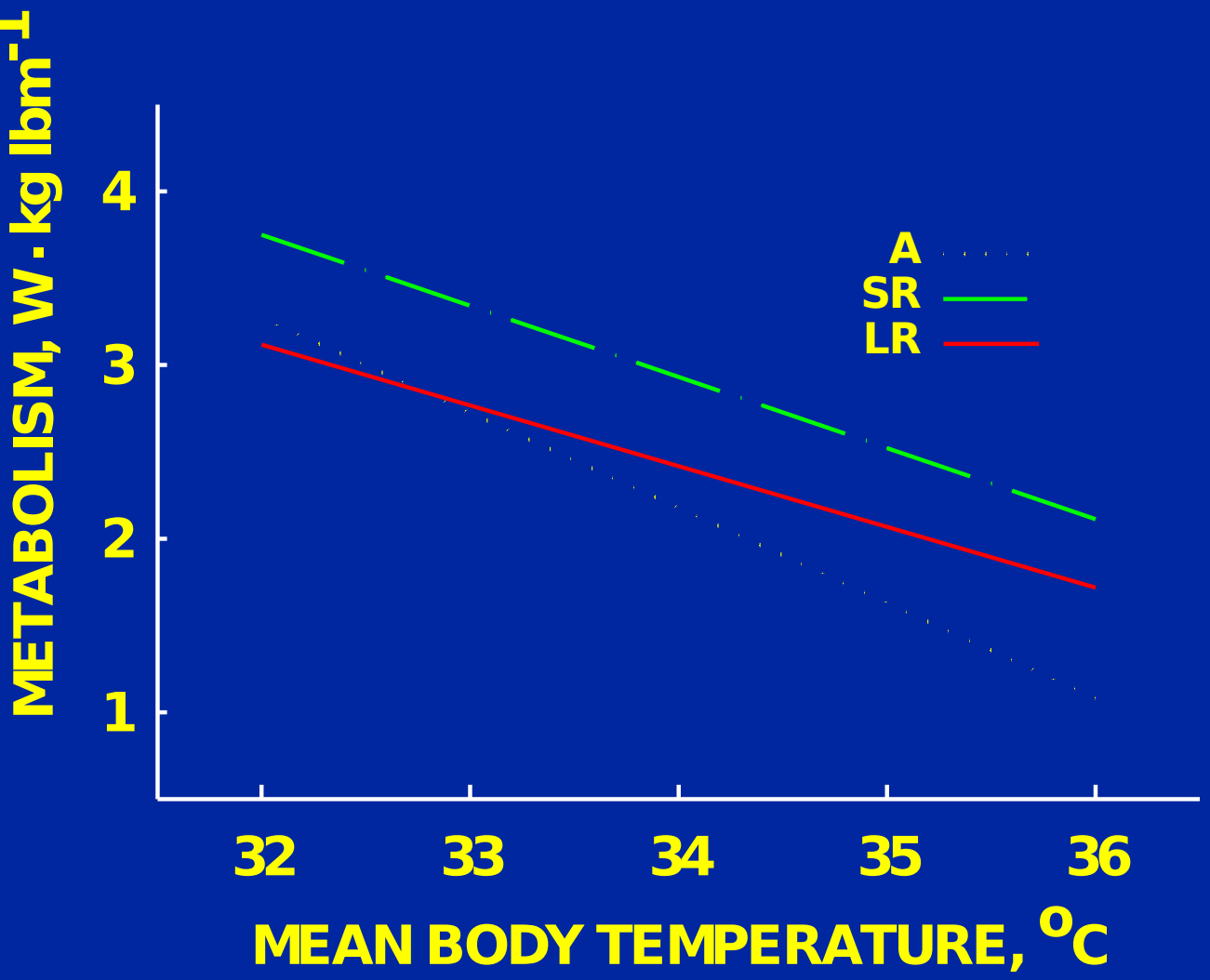
CORE TEMPERATURE CHANGES



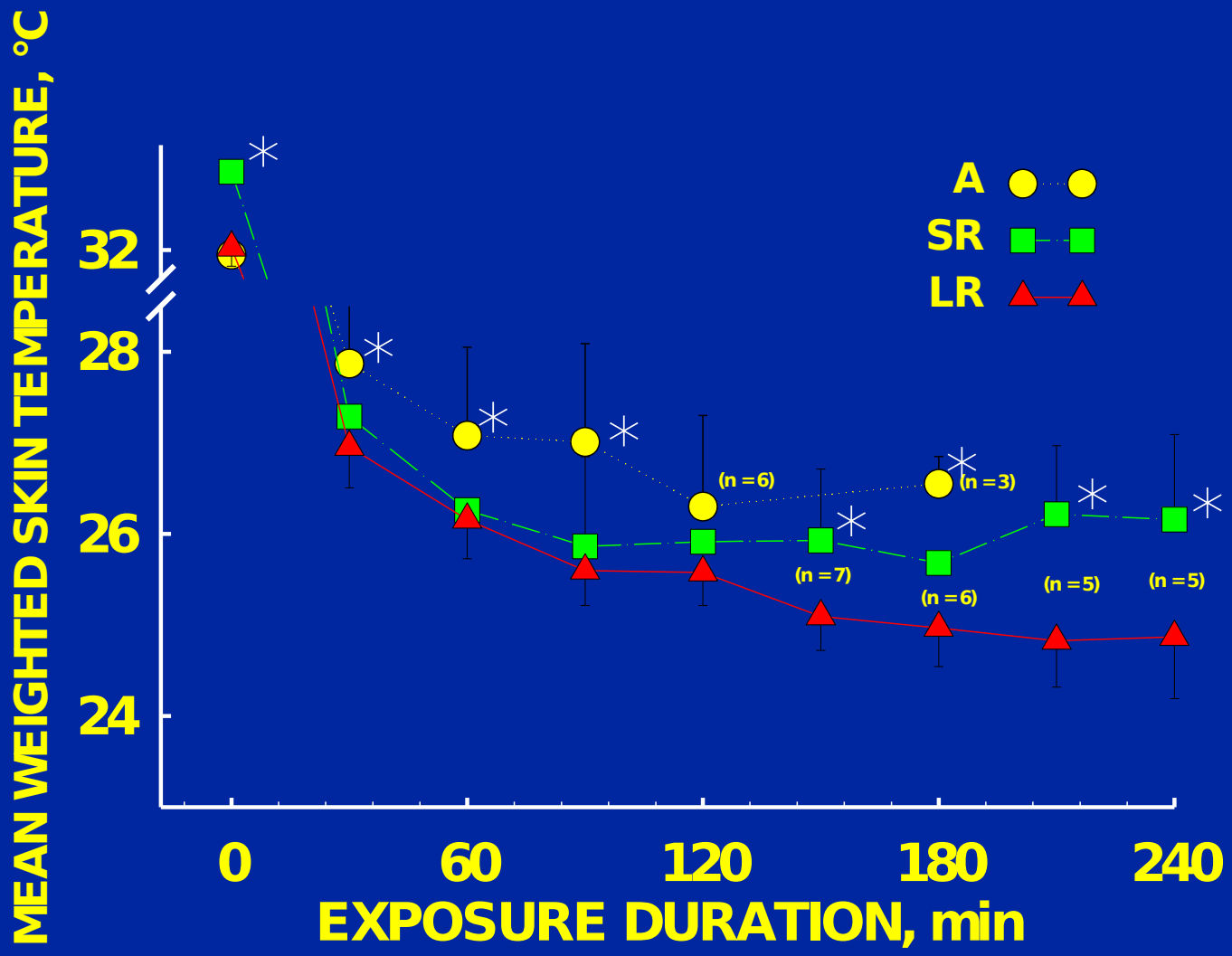
Shivering


METABOLIC HEAT PRODUCTION, W·m-2
120
100
80
60
40
0
60
120
180
240
EXPOSURE DURATION, min
(n = 6)
(n = 7)
(n = 5)
A
SR
LR

Shivering Suppression?



Skin Temperature Changes



MRMC - STO: Cold Injury Prevention Exhaustion & “Thermoregulatory Fatigue” during Cold Exposure

MRMC - STO: Prevention of Heat Injury

Validate New Fluid Replacement Guidelines for Hot Weather Training

RESEARCH QUESTIONS

Phase I:

Do thermoregulatory effector responses to cold "fatigue" during multiple cold exposures?

Phase II:

Do thermoregulatory effector responses to cold "fatigue" after acute exercise

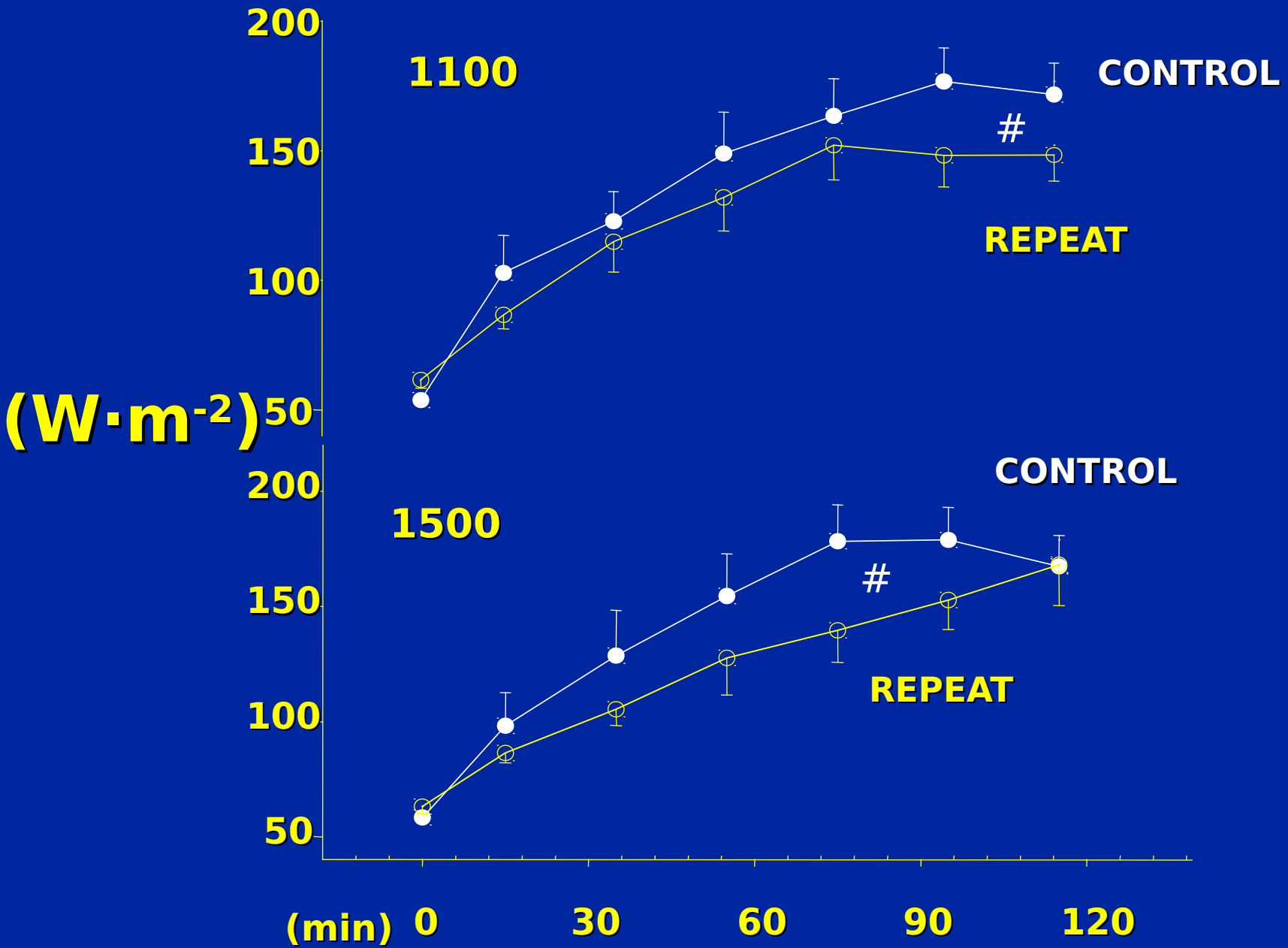
Phase III:

Do thermoregulatory effector responses to cold "fatigue" with chronic exertion or exercise-induced muscle damage?

STUDY 1: DO MULTIPLE EXPOSURES INCREASE RISK OF HYPOTHERMIA?

- Soldiers were immersed three times (2-h each time, H_20 = 68°F) in one day over a 10-h period.
- These immersions were compared to time of day controls.

METABOLIC HEAT PRODUCTION



Despite re-warming between immersions, multiple immersions caused:

- Decrease in Shivering
- Lower Core Temperatures
- Reduced Sense of Thermal Cues

Application: Soldiers immersed repeatedly may be at an increased risk of hypothermia.

(Castellani et.al. JAP 1999)

RESEARCH QUESTIONS

Phase I

Do thermoregulatory effector responses to cold "fatigue" during multiple cold exposures?

Phase II

Do thermoregulatory effector responses to cold "fatigue" after acute exercise

Phase III

Do thermoregulatory effector responses to cold "fatigue" with chronic exertion or exercise-induced muscle damage?

STUDY 2: DOES PRIOR EXERCISE INCREASE RISK OF HYPOTHERMIA?

120-m EXPOSURE TO 5°C AIR

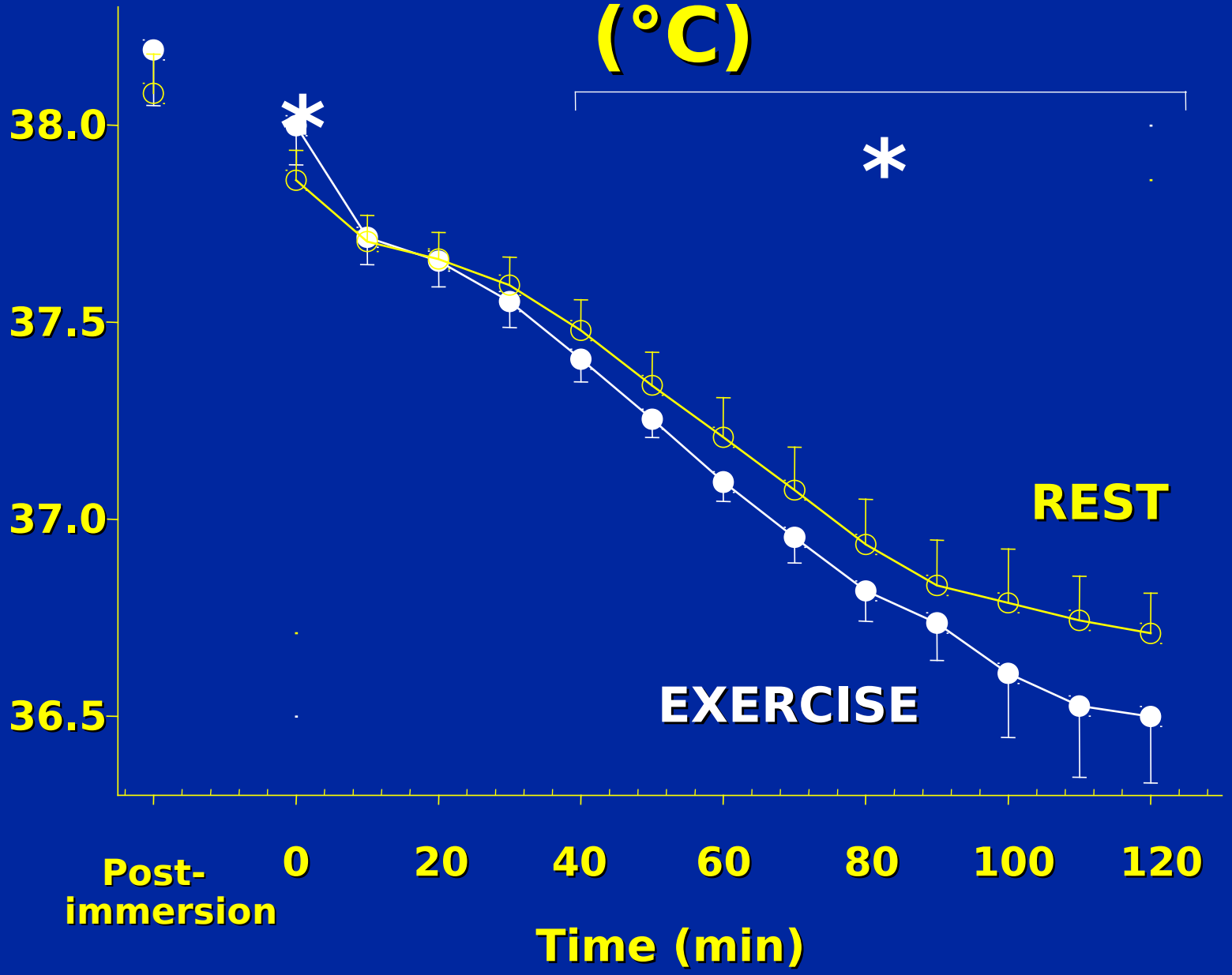
- Preceded by exercise 1-h in 35°C water

  (ΔT_{core} = 1°C)

- Preceded by rest in 38°C water

  (ΔT_{core} = 1°C)

CORE TEMPERATURE (°C)



EXERCISE BEFORE COLD EXPOSURE

- Greater Fall in Core Temperature
- Greater Peripheral Heat Loss

Application: Physically active soldiers suddenly immersed in cold water may be susceptible to hypothermia

(Castellani et.al. JAP 1999)

RESEARCH QUESTIONS

Phase I

Do thermoregulatory effector responses to cold "fatigue" during multiple cold exposures?

Phase II

Do thermoregulatory effector responses to cold "fatigue" after acute exercise

Phase III

Do thermoregulatory effector responses to cold "fatigue" with chronic exertion or exercise-induced muscle damage?

Cold/Wet Tolerance After 7-d Strenuous Exertion

Exercise (4h/day) for 7 days (Days 1-7)

3 mile run; 800-m runs; Weightlifting; Cycling; Stairstepping; Rowing; 30-s Anaerobic Power Test; 6 Mile hike

6-h WET WALK (5°C)

Days 0 (control), 3, 7

10 min rain (2 in/hr, 1.7 mph wind)

45 min walking (3 mph; 12 mph wind)

Measures of T_{re}, T_{sk}, M, blood metabolites, immune function

INDIVIDUAL SOLDIER RISK FACTORS

- Clothing, training and experience
- Illness, health and physical fitness
- Nutrition and hydration

U.S. ARMY RANGER TRAINING

62 DAYS, 19.5 HOURS/DAY

ENERGY EXPENDITURE - 4150 kCAL/D
ENERGY CONSUMPTION - 3300 kCAL/D

U.S. MCRD CRUCIBLE EXERCISE

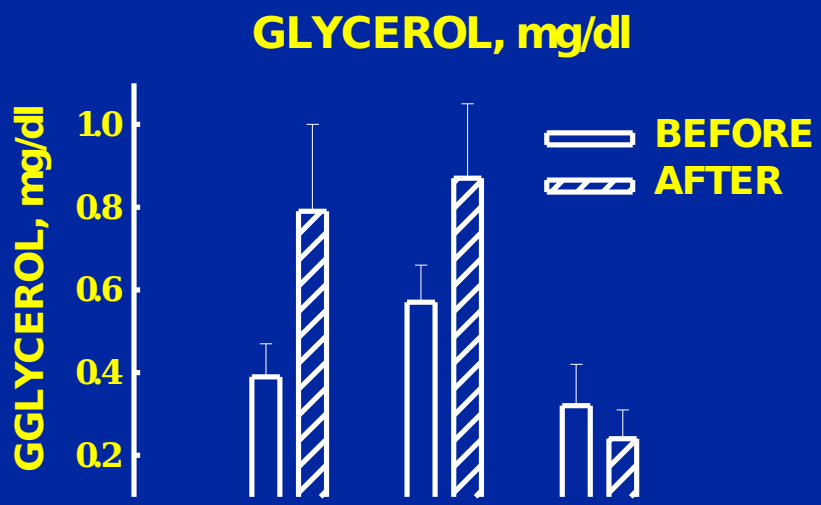
55 HOURS

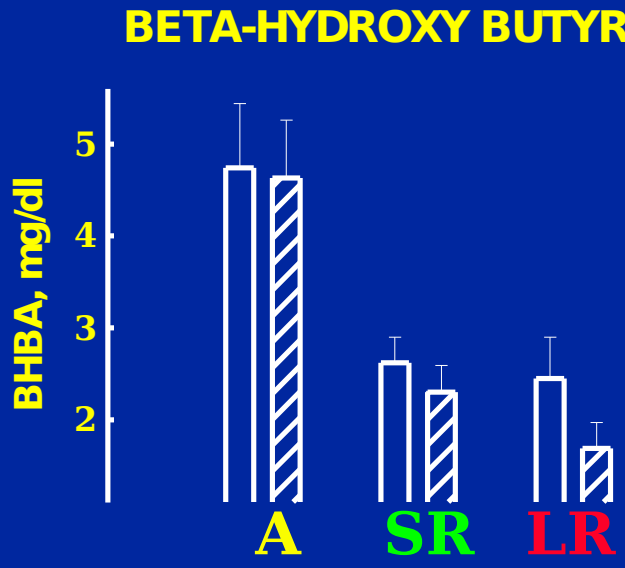
ENERGY EXPENDITURE - 5455 kCAL/D
ENERGY CONSUMPTION - 1338 kCAL/D

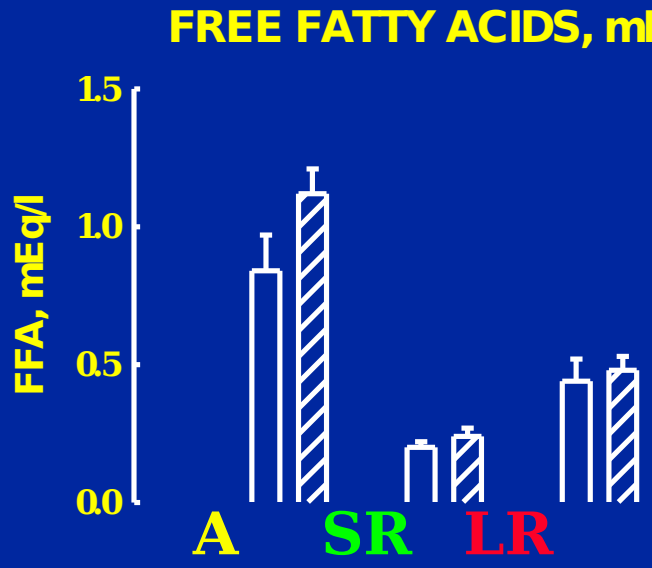
ACUTE DEPLETION OF ENERGY SUBSTRATES & SHIVERING

- **Hypoglycemia:**
  - ***Gale et al.*** **(1981) - insulin infusion - cold air**
  - **Shivering stops if blood glucose < 2.5 mmol/l**
  - **central not peripheral effect**
- **Muscle Glycogen Depletion:**
  - ***Young et al.*** **(1989) - shivering & heat balance unaffected**

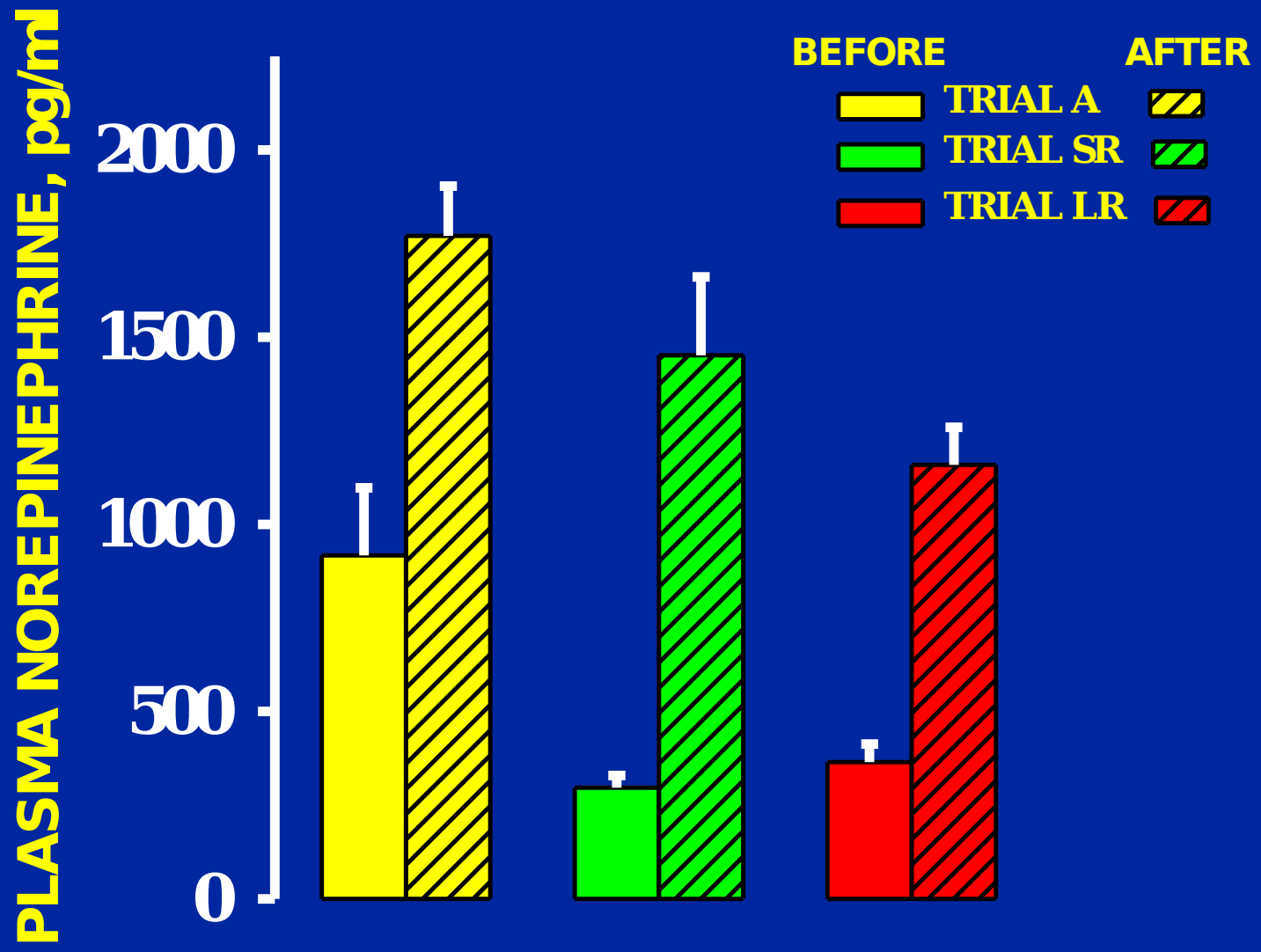
BLOOD METABOLITES



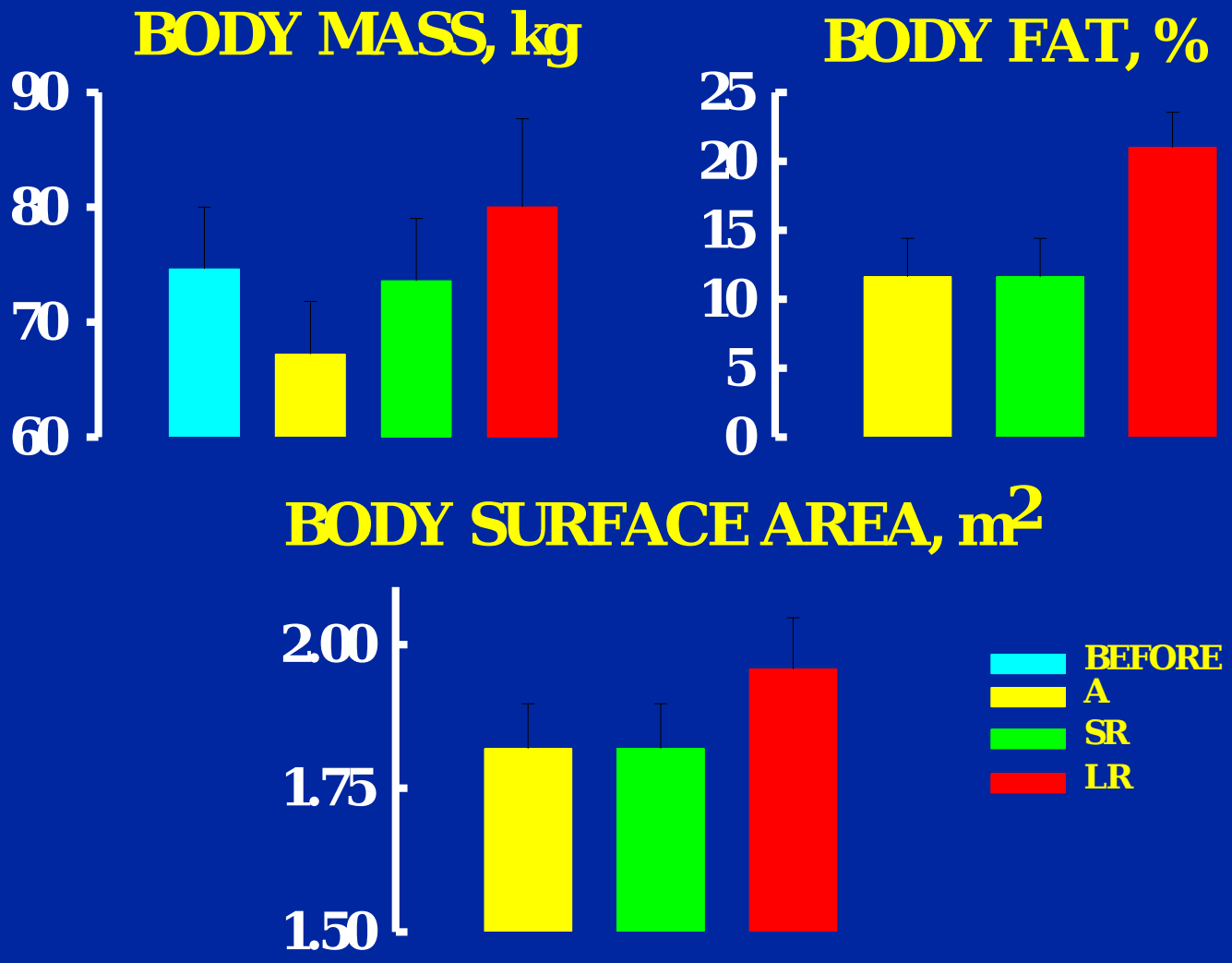




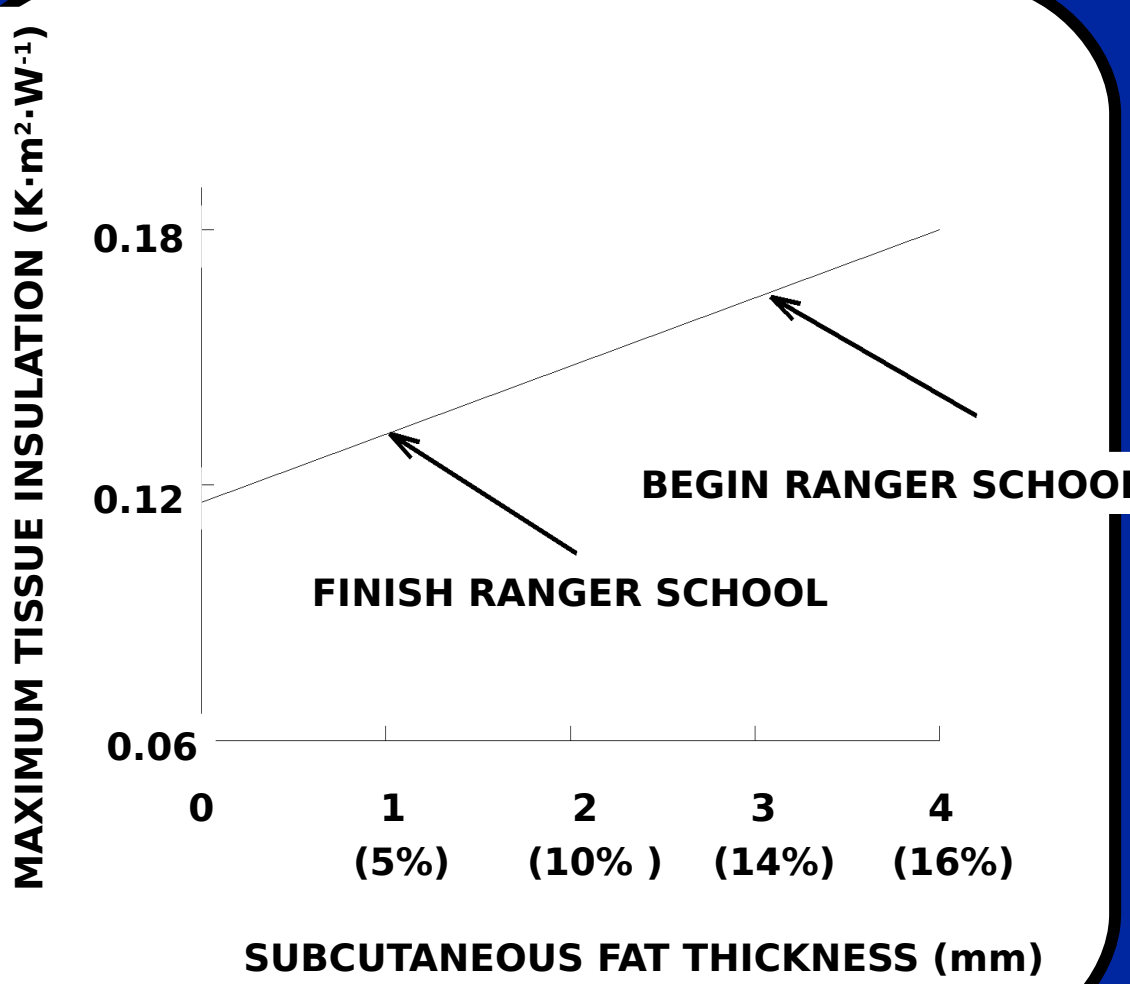
NOREPINEPHRINE CHANGES



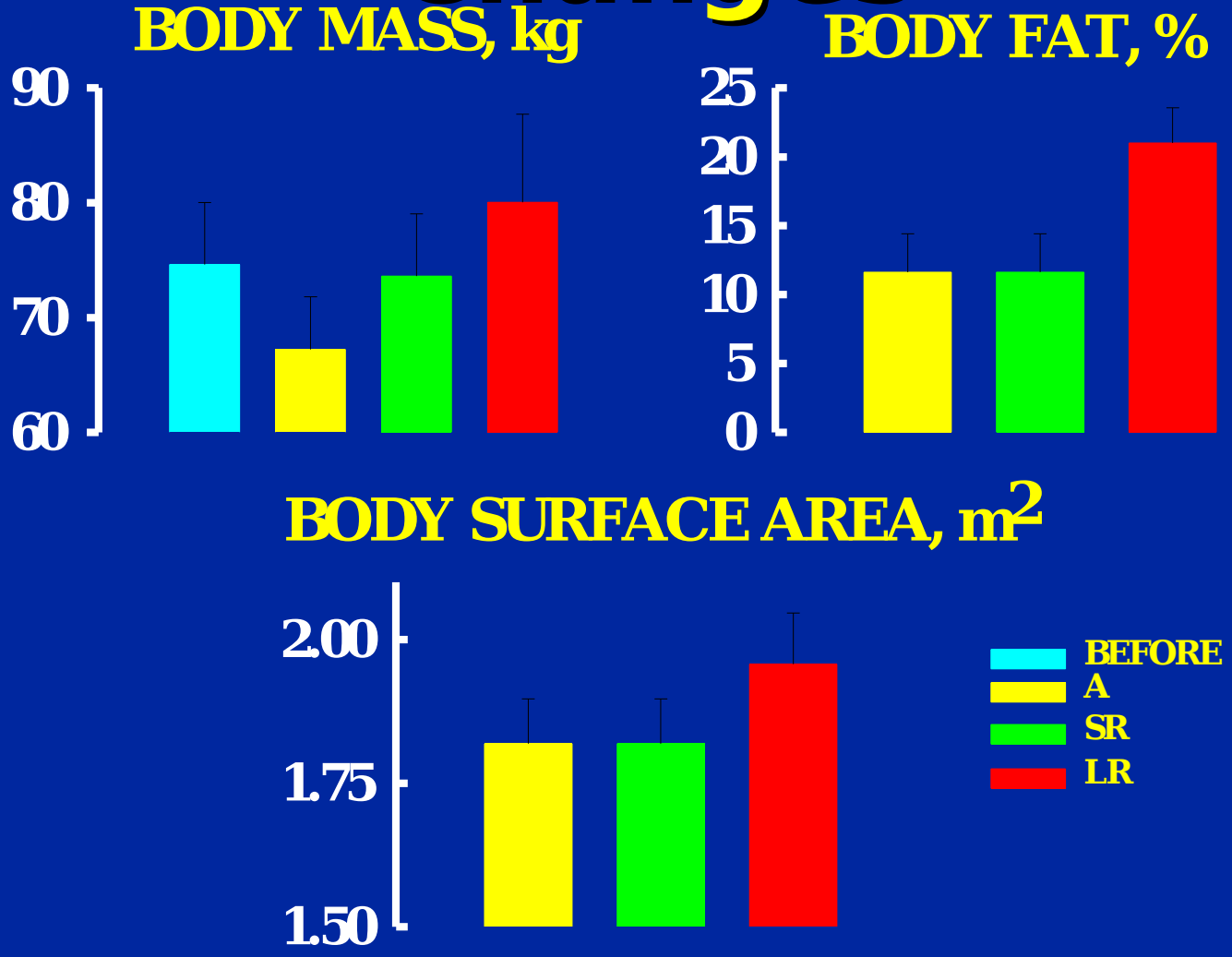
ANTHROPOMORPHIC CHANGES



FAT INSULATES



Anthropomorphic Changes



DOES DEHYDRATION IMPAIR THERMOREGULATION DURING COLD EXPOSURE?

- **Widely believed that dehydration increases susceptibility to cold injury**

- **Limited data concerning hand and finger cool**
- **No studies of hydration & whole body cold ex**

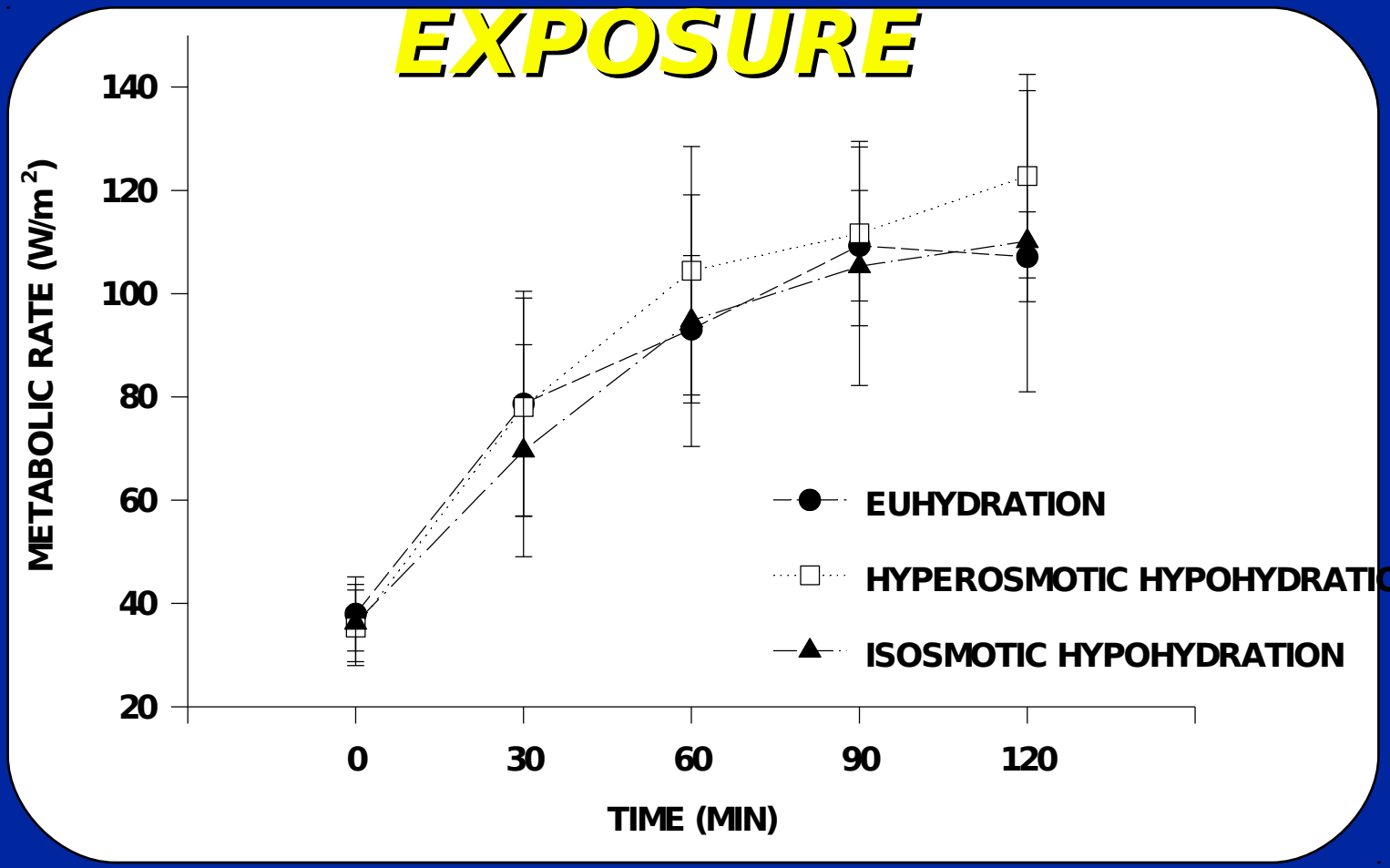
STUDY DESIGN

Three trials
Two hours resting supine in cold (5 °C) air

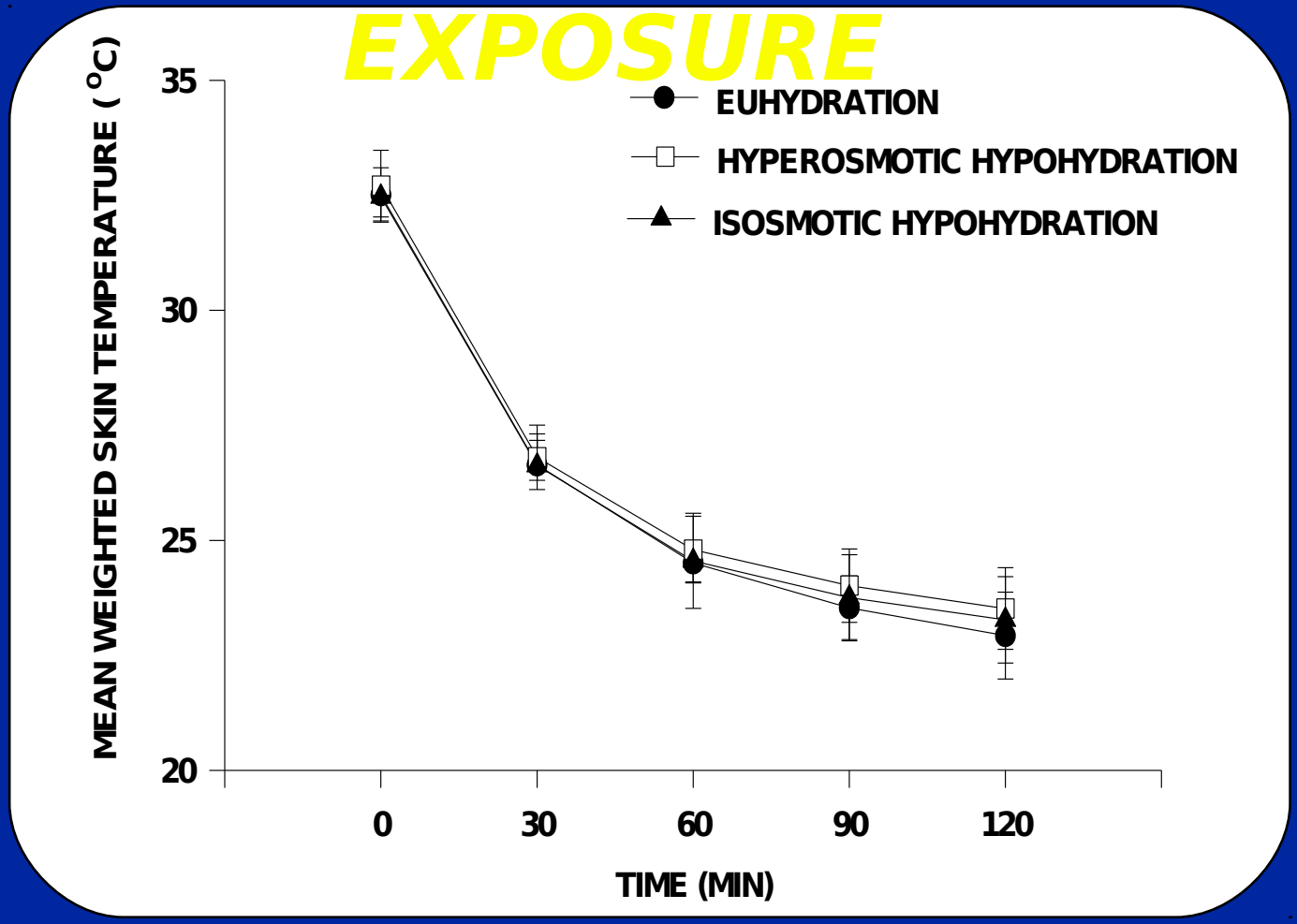
- **Euhydration**
- **Hypohydration, hypersosmotic (-5% bw, swea**
- **Hypohydration, isosmotic (-5% bw, furosemid**

9 healthy young men

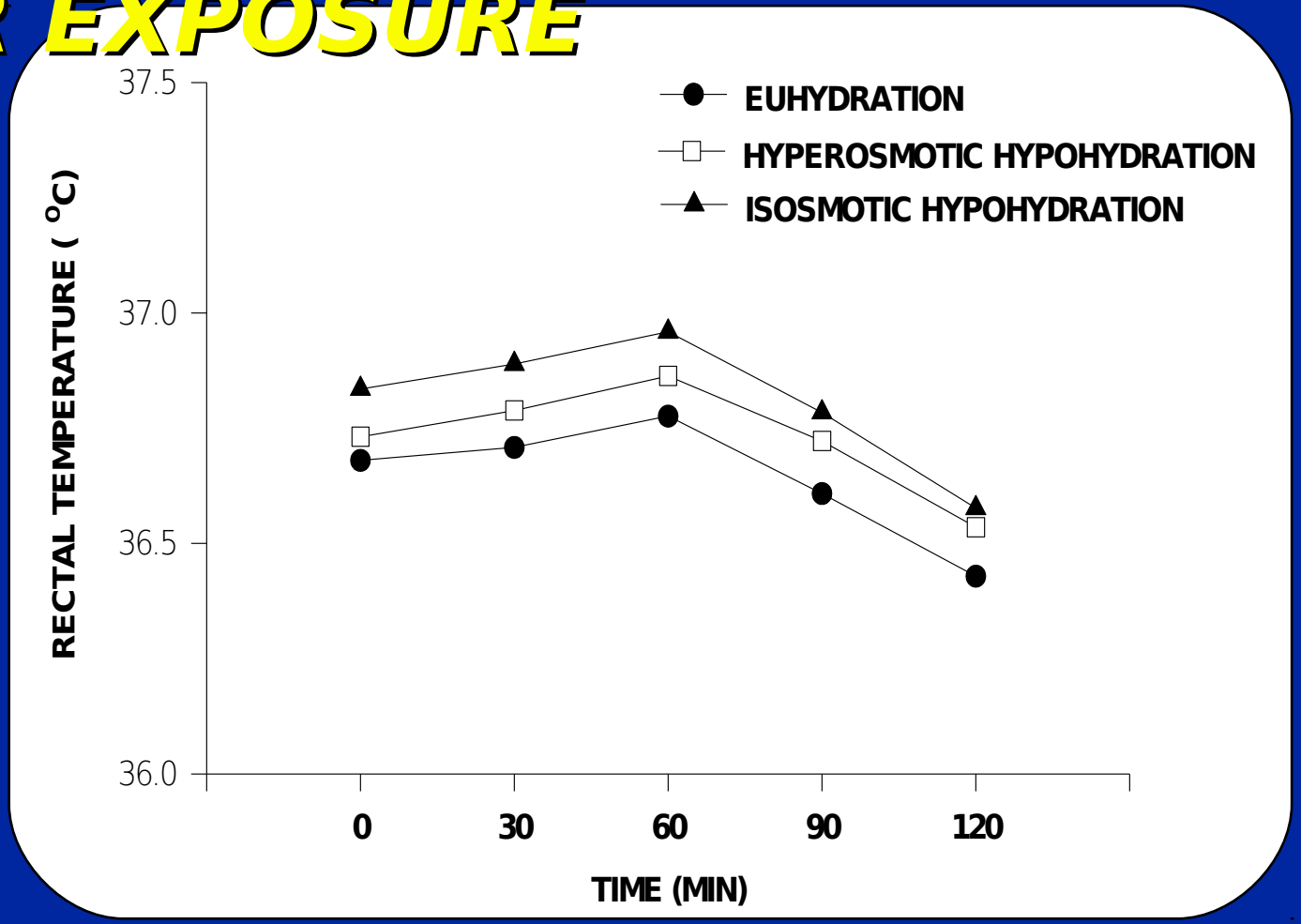
HYPOHYDRATION DID NOT AFFECT SHIVERING DURING WHOLE-BODY COLD AIR EXPOSURE



HYPOHYDRATION DID NOT AFFECT SKIN TEMPERATURE DURING WHOLE-BODY COLD AIR EXPOSURE



HYPOHYDRATION DID NOT AFFECT CORE TEMPERATURE DURING WHOLE-BODY COLD AIR EXPOSURE



HYDRATION & *WHOLE-BODY* COLD EXPOSURE

- ***Heat balance and thermoregulatory responses during whole-body cold exposure are unaffected by moderate levels of hypohydration***

- ***Finger & hand temperature changes during whole-body cold exposure were unaffected by hypohydration, in contrast to earlier work***

SUMMARY: HYPOTHERMIA RISK FACTORS DURING COLD-WEATHER TRAINING

- **ENVIRONMENTAL COOLING FACTORS**
  - WET
  - WIND
  - GROUND CONTACT
- **MISSION**
  - FATIGUE (EXERTION, SLEEP DEPRIVATION)
  - ACTIVITY LEVEL
- **INDIVIDUAL**
  - HEALTH
  - ENERGY DEFICIT (SIZE AND DURATION)

MANAGE COLD INJURY RISK WITH SOPs "TAILORED" TO TRAINING & WEATHER

- CLOTHING ISSUE
- TRAINING ALTERNATIVES/DEVIATIONS
- WET-FOR-DRY CLOTHING EXCHANGE
- REWARMING TENTS
- CWI SURVEILLANCE
- HOT RATION OR SUPPLEMENT

EXAMPLES: RTB COLD-WEATHER SOP; USARIEM TECH RPT T98-26 (MCRD CRUCIBLE RECOMMENDATIONS)

RESEARCH LEADS TO DECISION A

Field Study Data

Inputs

Real-Time Data

Verification

Development

Inputs

WSM

Safety Tables

Physiological Prediction Models

Mercury System

Development

Laboratory Data

Probabilistic ⟷ Deterministic

RISK MANAGEMENT APPROACH